

**d.) Remarks**

Applicant has amended claims 3, 10, 13, 26, 39, 43, 48, and 53. Most changes are typographical or grammatical corrections. Support for these amendments, where necessary, can be found throughout the specification and in the existing claims. No new matter is added or new issues raised by these amendments, and claims 1-69 are now pending.

**Remarks Regarding 35 U.S.C. § 112, Second Paragraph**

Claims 3, 10, 13, (and 39), 43 and 48 stand rejected, under 35 U.S.C. § 112, second paragraph, as allegedly indefinite. Applicant respectfully traverses this rejection.

With regard to claims 3 and 43, it is alleged that the recitation of “non-biosolid material that comprises class A biosolids” is contradictory and further that the phrase “class A biosolids” is unclear. First, the recitation of “non-biosolid” in both claims was a typographical error and the correct term should be “biosolids”. Appropriate correction has been made herein and this aspect of the rejection is moot. Second, the phrase “class A biosolids” is well known to those of ordinary skill in the art. A simple GOOGLE search on the Internet identified over 92,800 sites. Upon scanning through the first few dozen of these sites, all discussed various aspects of biosolids including recycling, processing, and organizations and associations working in the field of biosolid management and legislation. Further, the meaning of the term is disclosed in the specification wherein applicant states that a Class A biosolid can be defined in 40 C.F.R. 503.13 Table 3, EQ regulations (see specification, page 7, line 28). Thus, being both well known to those of ordinary skill in the art and disclosed in the specification, the term cannot be considered indefinite and this aspect of the rejection is overcome.

With regard to claims 10 and 48, it is alleged that the term “Eh” is not defined. Applicant respectfully notes that the term Eh is a typographical error and that the correct term is pH. Changes have been made where appropriate and this aspect of the rejection is moot.

With regard to claim 13, it is alleged that the term “encapsulating” should read encapsulates. This change has been made as suggested by the examiner and this aspect of the rejection is moot.

With regard to claim 39, it is alleged that the phrase “rotary hallow stem/trimmie placement” is unclear. This was a typographical error and the phrase has been corrected to “rotary hollow stem auger/trimmie placement” as set forth in the specification (see specification, page 9, line 17). In addition, these processes for the manufacture of granules are disclosed in U.S. Patent No. 6,258,589, which is attached hereto. Accordingly, this aspect of the rejection is moot.

Thus, the rejection of claims 3, 10, 13, (and 39), 43 and 48, under 35 U.S.C. § 112, second paragraph, is moot or overcome and applicant respectfully requests that it be withdrawn.

**Remarks Regarding 35 U.S.C. § 103(a)**

A. Claims 1-20, 27-57, 60, 68, and 69 stand rejected, under 35 U.S.C. § 103(a), as allegedly obvious over Waldman et al. (U.S. Patent No. 6,284,278; “Waldman”), Diping et al. (U.S. Patent No. 5,849,060; “Diping”), Cunningham (U.S. Patent No. 5,340,376), and Burger et al. (German Patent No. DE 41 27 459; “Burger”). Applicant respectfully traverses this rejection.

It is well established that to form a case of *prima facie* obviousness, the burden is on the Patent and Trademark Office (“PTO”) to provide sufficient evidence that would render the claimed invention obvious. *In re Piasecki*, 745 F.2d 1468 (Fed. Cir. 1984). A PTO rejection for obviousness is improper when there is nothing in the cited prior art references, either singly or in combination, to suggest the desirability of the claimed subject matter. *In re Deminski*, 796 F.2d 436 (Fed. Cir. 1986). In the instant rejection, not only is there no showing of the desirability of a modification to achieve biosolid-containing granules, there is no mention of biosolid-containing granules whatsoever.

The claimed invention is directed to granules comprising a core surrounded with one or more layers wherein the core, one or more of the layers, or both contain biosolid materials. Biosolids, such as Class A biosolids as disclosed in 40 C.F.R. Section 503.13, are well known by those of ordinary skill in the art. These are noxious materials typically organic sludge produced from municipal wastewater treatment facilities. None of the cited references disclose or suggest a granule containing biosolids. The references cited relate to defined chemical fertilizers, microorganisms that may be useful for bioremediation, or methods for the encapsulation of fertilizers and microorganisms.

As none of the cited references disclose or suggest, even inherently, granules containing biosolid materials, a *prima facie* case of obviousness has not been established and cannot be established from the cited references. Absent a *prima facie* showing of obviousness, this rejection must be withdrawn.

Thus, the rejection of claims 1-20, 27-57, 60, 68, and 69, under 35 U.S.C. § 103(a), is improper and applicant respectfully requests that it be withdrawn.

**B.** Claims 21-26, 58, 59, and 61-67 stand rejected, under 35 U.S.C. § 103(a), as allegedly obvious over Rogers et al. (U.S. Patent No. 6,465,706; “Rogers”), Turtakovsky et al. (U.S. Patent No. 6,051,411; “Turtakovsky”), and Resnick (U.S. Patent No. 5,807,724). Applicant respectfully traverses this rejection.

As discussed above, the claimed invention is directed to granules that contain a core and one or more layers, wherein the core, the one or more of the layers, or both contain biosolid materials. None of the cited references disclose or suggest granules containing biosolid materials. Although Turtakovsky does relate to microorganisms from homogenated anaerobic sludge (see abstract), there is nothing in this reference regarding biosolids. Turtakovsky is

directed to the immobilization of microorganisms (obtained from sludge) in a polymer gel matrix containing chitosan and lignosulphonate, which is unrelated to applicant's claimed invention.

A *prima facie* case of obviousness has not been established and cannot be established from the cited references. None disclose or suggest, even inherently, granules containing biosolid materials. Absent a *prima facie* showing of obviousness, this rejection must be withdrawn.

Thus, the rejection of claims 21-26, 58, 59, and 61-67, under 35 U.S.C. § 103(a), is overcome and applicant respectfully requests that it be withdrawn.

#### **Conclusion**

The application is in condition for allowance and the prompt issuance of a notice of allowance is respectfully requested. If there are any additional fees due with the filing of this Amendment, including any fees for an extension of time, applicant respectfully requests that extension and further requests that any and all such fees be charged to Deposit Account No. 03-1952.

Respectfully submitted  
MORRISON & FOERSTER, LLP,

Date: June 6, 2003

By: \_\_\_\_\_

James Remenick  
Registration No. 36,902

Morrison & Foerster, LLP  
1650 Tysons Boulevard; Suite 300  
McLean, Virginia 22102  
Telephone: (703) 760-7700  
Facsimile: (703) 760-7777  
**Customer Number 25227**

Enclosed: US Patent No. 6,258,589

USPTO PATENT FULL-TEXT AND IMAGE DATABASE

<a href="#">Home</a>	<a href="#">Quick</a>	<a href="#">Advanced</a>	<a href="#">Pat Num</a>	<a href="#">Help</a>
<a href="#">Hit List</a>		<a href="#">Previous</a>	<a href="#">Bottom</a>	
<a href="#">View Cart</a>		<a href="#">Add to Cart</a>		
<a href="#">Images</a>				

( 3 of 3 )

**United States Patent****6,258,589****Dybas , et al.****July 10, 2001**

Methods for providing a chemical to a microorganism

**Abstract**

A method and composition for microbial remediation or other treatment of chemicals is described. The method particularly uses solidified oils or oils impregnated into inert particles or particles which release nutrient medium over time.

Inventors: **Dybas; Michael J.** (Lansing, MI); **Criddle; Craig S.** (Lansing, MI); **Witt; Michael E.** (Holt, MI)

Assignee: **Board of Trustees operating Michigan State University** (East Lansing, MI)

Appl. No.: 177332

Filed: **October 22, 1998**

**Current U.S. Class:**

**435/262.5; 210/601; 210/610; 435/252.1**

**Intern'l Class:**

**B09B 003/00; C02F 003/00; C12N 001/12; C12N 001/20**

**Field of Search:**

**210/601,610 435/262.5,252.1**

**References Cited [Referenced By]****U.S. Patent Documents**

<u>3224946</u>	Dec., 1965	Raymond.	
<u>4039438</u>	Aug., 1977	Anderson.	
<u>5265674</u>	Nov., 1993	Fredickson et al.	
<u>5268109</u>	Dec., 1993	Boyd	210/691.
<u>5299638</u>	Apr., 1994	Cheneviere et al.	
<u>5340376</u>	Aug., 1994	Cunningham.	
<u>5348803</u>	Sep., 1994	Schlaemus et al.	
<u>5401413</u>	Mar., 1995	Gatt et al.	
<u>5560737</u>	Oct., 1996	Schuring et al.	
<u>5602036</u>	Feb., 1997	Criddle et al.	

5730550

Mar., 1998

Andersland et al.

**Other References**

Tatara, et al., Applied Environmental Microbiology, vol. 59, pp. 2126-2131 (1993).  
Markwell, et al., Methods of Enzymology, vol. 72, pp. 296-301 (1981).  
Criddle, et al., Applied Environmental Microbiology vol. 56, pp. 3240-3246 (1990).  
Dybas, et al., Applied Environmental Microbiology, vol. 61, pp. 758-762 (1995).  
Fletcher et al, Applied Environmental Microbiology, vol. 58, pp. 2954-2959 (1992).

*Primary Examiner:* Ware; Deborah K.

*Attorney, Agent or Firm:* McLeod; Ian C.

---

***Parent Case Text***

---

This application is a divisional application Ser. No. 09/061,305 filed on Apr. 16, 1998. This application claims priority to provisional application No. 60/044,090, filed Apr. 21, 1997.

---

***Claims***

---

We claim:

1. A method for providing a metabolizable chemical to a microorganism in the presence of water over a period of time which comprises:

introducing into the water an admixture of multiple particles which are water insoluble with micropores throughout each of the particles, the micropores of at least one particle containing a microorganism and the micropores of at least one particle containing a chemical selected from the group consisting of an electron acceptor, an electron donor, substances for modification of pH, a nutrient medium for the microorganism and mixtures thereof, and said chemical being metabolizable by the microorganism, wherein said chemical is exposed on a surface of each of the particles other than the particles containing the microorganism, and the particles containing the chemical release the chemical over a period of time to the particles containing the microorganism in the water such that the microorganism is able to metabolize the chemical over the period of time.

2. The method of claim 1 wherein the chemical in the micropores of the particles is a nutrient medium for the microorganism.

3. The method of claim 1 or 2 wherein the particles contain a vegetable oil as the chemical.

4. The method of claim 1 or 2 wherein the particles are made of clay.

5. A method for providing a metabolizable chemical to a microorganism in the presence of water over a period of time, which comprises:

introducing into the water inert and water soluble, particles with micropores throughout each of the particles, and further said particles having multiple channels which are less than about 0.1 to 100 microns in average diameter and having a size of about 0.1 to 50 millimeters, and the channels of at least one of the particles containing a microorganism and the channels of at least one of the particles containing the chemical selected from the group consisting of an electron acceptor, an electron donor, substances for modification of pH, a nutrient medium for the microorganism and mixtures thereof, and which said chemical is metabolizable by the microorganism, wherein said chemical is exposed on the surface of said at least one of the particles other than the particles containing the microorganism, and the chemical is further released over a period of time from the particles containing the chemical into the water to the particles containing the microorganism; and

metabolizing the chemical with the microorganism in the water over the period of time.

6. The method of claim 5 wherein the particles are clay.

7. The method of claim 5 or 6 wherein the particles contain a vegetable oil as the chemical in the micropores.

8. The method of claim 5 or 6 wherein the chemical in the micropores is a nutrient medium for the microorganism.

---

### *Description*

---

## BACKGROUND OF THE INVENTION

### (1) Field of the Invention

The present invention relates to a method using particles for providing pre-selected amounts of a chemical to a microorganism over time. In particular, the present invention relates to a particle for delivery of a nutrient to a microorganism which is released in small amounts over time from the particle. The method is particularly useful for bioremediation of contaminated sites in situ.

### (2) Description of Related Art

There is a need to deliver chemicals over time to a microorganism. The purpose can be to produce a chemical, such as an enzyme, or drug or to facilitate the growth of the microorganism.

Toxic compounds contaminating the environment can be converted into innocuous substances by microbial digestion of the toxic substances, referred to as bioremediation. Bioremediation has been used to treat soil in above-ground treatment systems, above-ground bioreactors, slurry pits, above-ground soil heaps, composting material, and in subsurface systems in situ.

The current methods for introducing remediation compositions into contaminated environments include injection of liquid or gas phase components into subsurface environments, extraction of liquid or gas phase components and treatment ex situ, or excavation of contaminated sites for treatment ex situ. These methods are labor intensive and expensive. It will become apparent that the prior art does not provide for an inexpensive, versatile and effective means for in situ remediation. The most closely related prior art is as follows.

U.S. Pat. No. 3,224,946 to Raymond relates to the use of zeolites to absorb the hydrocarbons to be degraded and then degrading the hydrocarbon with the microorganism. Specifically, this method uses hydrous aluminosilicate to act as a molecular sieve whereby hydrocarbonaceous material may become lodged until the material is released by chemical conversion by a bacteria. The method provides for an in vitro means for degrading hydrocarbonaceous material ex situ.

U.S. Pat. No. 4,039,438 to Anderson describes the use of pulp or paper as a substrate with bacteria to reduce nitrate in water.

U.S. Pat. No. 5,268,109 to Boyd describes the use of clays which have been ion exchanged to remove contaminants. The method does not relate to in situ remediation.

U.S. Pat. No. 5,265,674 to Frederickson et al relates to the introduction of oils and nutrients and optimally microorganisms into a zone to be remediated. The method effects remediation by pumping liquid oil into a contaminated site and allowing the oil to move throughout the soil concentrating and absorbing the contaminants. The oil containing the contaminants is then removed from the soil. An additional method provides for the addition of microbes to the oil applied to the site and allowing the microbes to degrade the contaminants concentrated by the oil. A limitation of this method is that the oil is applied to the remediation zone in liquid form. In liquid form, the dissolution of the oil is fairly rapid therefore, requiring repeated applications to effectively remove the contaminants.

U.S. Pat. No. 5,299,638 to Cheneviere et al relates to the use of clays or other porous materials with bacteria to produce viscosity promoting polymers.

U.S. Pat. No. 5,340,376 to Cunningham relates to the controlled release of nutrients with a timed release coating. Once the coating is gone, the nutrient is released. The invention provides for remediation by providing nutrients for the bacteria fauna already present which then degrade the contaminating organic compounds. The nutrients are provided as granules of urea coated with a resin which when introduced into a site continuously provide nutrients for up to three months. The limitation of the invention is that it relies on the naturally occurring bacteria fauna already present at the contaminated site. If the site does not provide the bacterial species that are capable of degrading the offending contaminant or in sufficient numbers then the invention will not be effective for remediation. Furthermore, the composition and method were designed for surface level remediation wherein the composition is tilled into the soil.

U.S. Pat. No. 5,348,803 to Schlaemus et al relates to microcapsules of microorganisms and hydrocarbons as nutrients. This invention is an improvement over the previous invention in that capsules having a water insoluble coating containing a microorganism capable of degrading hydrocarbons surrounds a core that provides nutrients for the microorganism. The invention is designed to be sprayed on oil spills in an aqueous environment whereby the microcapsules being water insoluble remain associated with the oil.

U.S. Pat. No. 5,401,413 to Gatt et al relates to microorganisms and exposures for bioremediation. The invention provides a composite material having a core containing water soluble microbial nutrients and a partially oil soluble and biodegradable coating. The composite material is sprayed or dusted onto an oil spill whereby the oil soluble coating causes the composite to associate with the oil contamination.

U.S. Pat. No. 5,602,036 to Criddle et al relates to metabolites of *Pseudomonas* which enhance bioremediation. Metabolites produced by *Pseudomonas* are introduced into a material containing a halogenated hydrocarbon and an indigenous or added bacterium to effect degradation of the halogenated hydrocarbon by the bacterium.



U.S. Pat. No. 5,560,737 to Schuring et al relates to pneumatic fracturing and introduction of microorganisms or nutrients into the fracture.

U.S. Pat. No. 5,730,550 to Andersland et al describes the use of a freeze wall for placement of a bioremediation method in situ.

The problem with this prior art is that an effective method for placement of the long term or time (months) released nutrients and/or microorganisms in situ is not described. This limitation and other limitations of the prior art will become more apparent from the discussion that follows.

## Objects

It is therefore an object of the present invention to provide novel forms of particles which release nutrients over time as needed by the microorganisms. It is further an object of the present invention to provide a method which is easy to perform and which is economical. These and other objects of the present invention will become increasingly apparent by reference to the following description and the drawings.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a graph showing the cumulative mass of  $\text{CCl}_4$  removed and  $\text{CHCl}_3$  produced by *P. stutzeri* KC using a prior art method.  $\text{CCl}_4$  was added initially and on day 3. Error bars for the mass of  $\text{CCl}_4$  added represent the cumulative error of addition. Error bars for experimental samples represent a standard deviation of three independently grown cultures. The graph shows that this method is particularly effective.

FIG. 2 is a graph showing the cumulative mass of  $\text{CCl}_4$  removed and  $\text{CHCl}_3$  produced by an enrichment of organisms from Schoolcraft aquifer solids.  $\text{CCl}_4$  was added initially and on day 3. Error bars for the mass of  $\text{CCl}_4$  added represent the cumulative error of addition. Error bars for experimental samples represent a standard deviation of three independently grown cultures. The graph shows that this microorganism is particularly effective.

FIG. 3 is a graph showing the transformation of Carbon tetrachloride by *P. stutzeri* KC in aquifer solid/groundwater slurries when provided hydrogenated cotton seed oil beads by the method of the present invention.

FIG. 4 is a graph showing nitrate removal by *P. stutzeri* KC when provided hydrogenated cotton seed oil beads as the carbon source.

FIG. 5 is a graph showing Carbon tetrachloride degradation by *P. stutzeri* KC grown on microporous beads of the present invention which provide nutrients base, phosphate, acetate, vegetable shortening and strain *Pseudomonas stutzeri* KC and which are introduced into aquifer material/groundwater slurries via microprobes clay fractured beads.

FIG. 6 is a graph showing the effect of the microporous beads on pH of aquifer material/groundwater slurries due to the base.

FIG. 7 is a graph showing the effect of microporous clay beads on the fluid conductivity of sand.

FIG. 8 is a graph showing concentration of carbon in the liquid with time using beads impregnated with vegetable oil (values represent average of triplicates, error bars represent standard deviation).

## DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention relates to a method for providing a chemical to a microorganism over time which comprises: providing particles containing the chemical utilizable by a microorganism and exposed on a surface of each of the particles, wherein particle can release the chemical over an extended period of time to the microorganism in water; and introducing the particles in the presence of water, so that the microorganism is able to utilize the chemical.

The present invention relates to a method for providing a chemical to a microorganism over time, which comprises: providing particles which comprise an inert and water insoluble particle having multiple channels which are less than about 0.1 to 100 microns in average diameter and having a size of about 0.1 to 50 millimeters; and a chemical provided in the channels which is utilizable by the microorganism, which chemical is exposed on the surface of each of the particles and is released over time from the particle in an aqueous environment to be utilized by the microorganism; and introducing the particle into the aqueous environment with the microorganism so that the chemical is released to the microorganism.

The present invention also relates to a method for remediating a zone of contamination in situ in the earth containing water by injecting a nutrient medium for a microorganism into the zone, the improvement which comprises: injecting the nutrient medium into the zone in particles with the nutrient medium exposed on a surface of each of the particles, and within the channel structure and which release the nutrient medium into the water in the zone so that microorganisms in the zone are provided with the nutrient medium over an extended period of time.

The present invention relates to a composition which comprises multiple particles which are impregnated with one of (1) a microorganism which chemically modifies a compound, (2) an electron acceptor, (3) an electron donor, (4) substances for modification of pH or (5) a nutrient medium for the microorganism which are exposed on a surface of each of the particles and are releasable over time in situ in an aqueous environment.

The present invention relates to a composition which comprises particles containing a nutrient medium for a microorganism exposed on a surface of the particles, wherein the particles release at least two chemicals on separate particles over an extended period of time to the microorganism in the presence of water.

The present invention relates to particles for providing a chemical to a microorganism over time which comprises: inert and water insoluble particles having multiple channels which are less than about 0.1 to 100 microns in average diameter and having a size of about 0.1 to 50 millimeters; and a chemical provided in the channels which is utilizable by the microorganism, which is exposed on a surface of the particles and which is released over time from the particles in an aqueous environment to be utilized by the microorganism.

### Definitions

Bioremediation--The term "bioremediation" means the process of treating a noxious substance (a toxic or unwanted chemical or compound) with a microorganism that is capable of digesting, detoxifying, or converting the chemical or compound to a less toxic or non-toxic chemical or compound thereby removing the offending substance.

Contaminant--The term "contaminant" means a composition which is environmentally unwanted in soil or water. Examples of contaminants are organic chemicals such as carbon tetrachloride, nitrates,

aliphatic hydrocarbons, aromatic hydrocarbons, including halogenated aromatic, polynuclear aromatic, polychlorinated biphenyl, trichloroethylene, perchloroethylene, various pesticides, various herbicides, and any other chemical deemed to be bioremediable.

In situ--The term "in situ" means in place.

**Remediation**--The term "remediation" means to change the physical or chemical composition of a contaminant in the soil or water.

**Electron Donor**--The term "electron donor" means a chemical composition that is capable of donating electrons, such as reduced transition metals, sulfur, and organic substances.

**Electron Acceptor**--The term "electron acceptor" means a chemical composition that is capable of accepting electrons such as oxygen, nitrate, ferric iron or other oxidized transition metals.

Treatment or Remediation Zone or Remediating a Zone--The terms "treatment zone or remediation zone or remediating a zone" means a volume in the ground which has been filled with a treatment composition.

Delivery control--The term "delivery control" is defined as a means that allows control of the rate a substance is delivered such means including co-precipitation, diffusion, or timed release coating.

Co-precipitation--The term "co-precipitation" means a method wherein desired substrates are delivered to the remediation zone as precipitates that dissolve at a controlled rate.

**Diffusional Path Tortuosity**--The term "diffusional path tortuosity" means a complex flow path within a particle wherein the complexity of the structure of the particle affects the rate of diffusion of a desired substance into the remediation zone.

Timed Release Coating--The term "timed release coating" means a substance that surrounds a solid particle and that dissolves at a particular rate to release the contents of the particle, the rate dependent on the thickness of the coating. Examples of timed release coatings that can be used to control the time the contents of a particle are released in a bioremediation environment include polyethylene, polypropylene, polyacrylamide, ethylene, propylene copolymer, ethylene vinyl acetate copolymer, vinylidene chloride, vinyl chloride, vinylidene chloride-vinyl chloride copolymer, polystyrene, and biodegradable polymers such as agarose.

Bead--The term "bead" means a particle or substance having a round or irregular shape that can be made of clay, a polymer, or comprised of an innocuous oil such as cotton seed oil or corn oil that has been hydrogenated to make the oil a solid.

**Microporous particle--**The term "microporous particle" means a bead or particle having a round or irregular shape that has micropores or microfissures or channels throughout defining a matrix, the micropores or microfissures being necessary for adsorbing the desired substance and being capable of delivering the desired substance wherein the rate of delivery is dependent on the size of the microporous particle, and the complexity of the structure of the particle wherein the size and number of the micropores or microfissures, and the interconnectedness or matrix of the micropores or microfissures throughout the particle affect the complexity of the particle's structure. Microporous particles can be produced from compounds such as clay or polymers.

Particle--The term "particle" means a solid substance either a bead having either a round or an irregular

shape that can be made of clay, hydroxy apatite, a polymer, or a hydrogenated innocuous oil.

Innocuous oil--The term "innocuous oil" means any oil that is non-toxic.

Microorganism--The term "microorganism" means any microbial species such as bacteria, yeast, or fungi known or further discovered (e.g. such as mixtures of microorganisms present in and isolated from natural flora) that is capable of metabolizing a toxic chemical or compound. Examples of microorganisms that are useful, include but are not limited to, *Pseudomonas stutzeri* strain KC, *Nocardia salmonicolor*, *Nocardia globerula*, *Nocardia paraffinae*, *Nocardia poaca*, *Pseudomonas putida*, *Pseudomonas oleovorans*, *Pseudomonas aeruginosa*, *Pseudomonas fluorescens*, *Mycobacterium phlei*, *Mycobacterium lacticola*, *Mycobacterium paraffinicum*, *Aerobacter aerogenes*, *Bacillus subtilis*, *Sacharomyces cerevisiae*, *Bacterium acidipropionci*, *Bacterium aliphaticum liquifaciens*, *Arthrobacter paraffinens*, *Rhodococcus rhodochrous*, *Acinetobacter calcoaceticus*, the various *Azotobacter* sp., *Bacillis* sp., *Clostridium* sp., *Fusarium* sp., *Candida* sp., *Flavobacterium* sp., *Corynebacterium* sp., *Achromobacter* sp. *Acinetobacter* sp., *Rhodococcus* sp., *Pseudomonas* sp., *Mycobacterium*, *Nocardia* sp., *Rhodotorula* sp., filamentous fungi such as *Penicillium* sp. and *Phycomyces* sp., and *Apergillus* sp., *Streptomyces griseus*, among others. Further, the term "microorganism" means naturally occurring fauna in the soil. Further still "microorganism" means microorganisms that have been genetically engineered to metabolize or improve its ability to metabolize toxic chemicals and compounds. Finally, microorganism may mean enzymes that can degrade unwanted chemicals.

Nutrient medium--The term "nutrient medium" means any nutrient that supports growth of a microorganism. Examples of nutrient media include but are not limited to biological buffers, carbon sources, electron donors, alkalinity causing agents, electron acceptors such as ferric iron or nitrate, energy sources such as glucose, and compounds produced by one microorganism that induce a second microorganism to remediation activity.

Metabolizable Chemical--The term "metabolizable chemical" means any chemical modified by a microorganism.

Environmental Amendments--The term "environmental amendments" means any chemical, biological or microorganism that is introduced into the environment.

In situ remediation has the potential for providing low cost treatment options for environments contaminated with hazardous wastes. The biological treatment options provide a means of treating hazardous materials without the need for extraction or evacuation of contaminated materials. Bioremediation (both biostimulation and bioaugmentation) requires periodic or continuous introduction of nutrients or buffers to sustain active populations of bacteria, capable of degrading hazardous wastes in situ. For treatment of many sites, delivery of nutrient(s) or other environmental modifiers may be needed over sustained periods of time. The present invention provides an inexpensive means of delivering controlled levels of nutrients to maintain active microorganism populations, or chemical reactants to effect degradation over extended periods of time. This is performed by delivering a particle capable of delivering via dissolution the nutrients, environmental modifiers and/or reactants capable of biologically remediating an environment contaminated with hazardous materials.

Polymer--The term "polymer" means any compound that has been polymerized to form a rigid structure and such compounds may be manufactured from polyethylene, polypropylene, polyacrylamide, ethylene, propylene copolymer, ethylene vinyl acetate copolymer, vinylidene chloride, vinyl chloride, vinylidene chloride-vinyl chloride copolymer, polystyrene, and biodegradable polymers such as agarose.

In situ remediation has the potential for providing low cost treatment options for environments contaminated with hazardous wastes. The biological treatment options provide a means of treating hazardous materials without the need for extraction or evacuation of contaminated materials. Bioremediation (both biostimulation and bioaugmentation) requires periodic or continuous introduction of nutrients or buffers to sustain active populations of bacteria, capable of degrading hazardous wastes in situ. For treatment of many sites, delivery of nutrient(s) or other environmental modifiers may be needed over sustained periods of time. The present invention provides an inexpensive means of delivering controlled levels of nutrients to maintain active microorganism populations, or chemical reactants to effect degradation over extended periods of time. This is performed by delivering a solid phase material capable of delivering via dissolution the nutrients, environmental modifiers and/or reactants capable of biologically remediating an environment contaminated with hazardous materials.

A novel feature of this invention is the use of control of diffusion rates of the delivered substrates to achieve desired in situ concentrations. The delivery control is achieved by 1) selection of appropriate chemical forms of the needed substrates with environmentally compatible initial dissolution properties, which initial properties are further enhanced by 2) use of porous particle matrices to control surface area for diffusion delivery, and 3) use of time dissolving or condition specific dissolving coatings of particles to control serial release of substrates over long time duration or with appropriate delivery cycle. These mechanisms will allow control of contact time of the delivered substrate in the environment.

The invention provides a series of particle formulations to achieve process specific delivery of the required substrates to effect bioremediation. These could include, microorganisms, nutrients, and any other substrates that are necessary for biological in situ remediation of hazardous waste. Any potential combination of required substrates could be delivered if a suitable carrier bead or formed bead of sufficient compression strength and appropriate size can be achieved.

Current means capable of introducing the particles of the present invention are 1) jet grout drilling introduction, 2) *rotary hollow stem* auger/trimmie slurry introduction, 3) hydraulic fracturing and 4) freeze placement. Jet grouting utilizes high pressure delivery into the subsurface to "fluidize" the formation and allow introduction of materials. Rotary hollow stem/trimmie placement involves pumping slurried materials into the subsurface annulus of the borehole. Hydraulic fracturing utilizes low pressure delivery of a slurry to create vertical or horizontal fractures in the subsurface. Hydraulic fracturing will enable delivery of the particles of the present invention when lower shear and pressures are needed to preserve particle integrity. Freeze wall placement would allow direct introduction of the particles of the present invention into a confined zone of the subsurface.

An object of the present invention is particle formulations that achieve delivery control by means of co-precipitation, wherein the substrates are delivered as a controlled solubility precipitate. This process can utilize hydrogenated cotton seed oil spheres or beads or particles of the present invention which are produced by Aveka, Inc. (Minneapolis, Minn.) to deliver carbon to support growth and carbon tetrachloride degradation by *Pseudomonas stutzeri* strain KC. These solid beads may also be formulated with hydrogenated derivatives of other innocuous oils, an example being hydrogenated corn oil. The solid oil beads may range in size from 10  $\mu\text{m}$  to 3 mm in diameter. The preferred size of beads demonstrated in Example 2 was approximately 300 microns in diameter. The size of the solid oil beads determines the length of time the carbon source provided by beads will persist and supply carbon to the microorganisms. Large beads will provide a carbon source for the microorganisms for a longer period of time than smaller beads. This makes it possible to control the length of time the carbon source is to be provided to the microorganisms simply by adjusting the size of the beads. For long duration remediation zone projects the beads will be larger than beads used for short term remediation zone projects.

The use of the solid oil beads of the present invention are an improvement over prior art methods of

providing oil to the soil in liquid form because the liquid oil rapidly dissipates, thereby losing its effectiveness as a carbon source for the microorganisms and the rapid depletion of the oil can result in the generation of unwanted degradation by-products. For long term remediation zone projects, at additional expense, liquid oil would have to be periodically reinjected into the site to maintain a carbon source for the microorganisms.

Additional particle formulations of the present invention to achieve delivery control include control of diffusional path tortuosity, which is a means for limiting the rate of diffusion of a desired substrate by requiring diffusion via of a complex flow path from within a particle. This process can utilize microporous clay beads or particles of the present invention which are manufactured by Einfach-Grün Hydroton (Eschborn, Germany) to deliver to a remediation zone either simultaneously or differentially such substances may be a carbon source, an electron donor, nutrients, such as phosphate, an electron acceptor, an acidity or alkalinity source such as potassium phosphate for pH control, and microorganisms. These microporous beads may also be manufactured from polymers, preferably polymers that are biodegradable. The preferred size of microporous clay beads ranged in size from 4 mm to 8 mm. The pores of the beads may be as narrow as 0.22  $\mu\text{m}$ ; however, for most purposes the pores will be greater than 1  $\mu\text{m}$ . The complex flow path of the microporous beads may be interconnected micropores, channels or microfissures or both throughout the bead. The smaller and more complex the micropore network the slower the rate of diffusion. Additionally, the larger the particle size, the more material that can be contained therein, and the longer the microporous beads may provide their contents to the soil. Furthermore, microporous beads have a high compression strength and therefore may be applied to a remediation zone using high pressure application methods.

The microporous beads of the present invention are an improvement over prior art methods for remediation in that beads containing a carbon source, beads containing microorganisms, beads containing nutrients, such as phosphates, beads containing an electron acceptor source such as ferric iron, beads containing an electron donor, such as sulfur, and beads containing an alkalinity or acidity source for pH control may all be provided simultaneously or differentially to a remediation zone. Providing microporous beads that enable control of pH is of particular importance in that a niche that is capable of supporting the desired microorganism for degrading a contaminant can be achieved in an environment containing a diverse flora of microorganisms. For example, adjusting the pH of an environment with an alkali such as KOH and then introducing *Pseudomonas stutzeri* strain KC into the environment, allows the introduced *P. stutzeri* KC to compete more effectively against the indigenous microorganisms for nutrients and allowing *P. stutzeri* to express activities, such as the activity for breaking down carbon tetrachloride to carbon dioxide, in the presence of indigenous soil microorganisms. Introducing an alkali to change the pH of the site to be remediated increases the effectiveness of bioremediation and in some cases may accelerate the bioremediation process.

Current means of introducing remediation agents into contaminated environments include injection of liquid or gas phase components into subsurface environments, extraction of liquid or gas phase components and treatment ex situ, or excavation of contaminated solids. These options are all expensive, both for installation of the injection/extraction systems, and for the operation. In the present invention delivering nutrients or reactants which slowly dissolve in situ, eliminates or reduces the capital costs of drilling and installing wells, pumping systems, or barriers to direct flow. The present invention allows the establishment of a permeable reaction "curtain", or reaction wall to be introduced in the path of a contaminant plume. The reaction curtain is constructed so as to allow unimpeded flow of contaminated groundwater while ensuring sufficient contact with the agents of remediation. Various construction methods, such as jet grouting or vertical hydraulic fracturing, can be employed for placement of the remediation agents of the present invention.

To effect remediation the preferred process of the present invention provides for the loading of porous

In the following Examples, all chemicals used were ACS reagent grade. All water used in reagent preparation was 19 Mohm resistance or greater. CCl<sub>4</sub> (99%--purity) was obtained from Aldrich Chemical Co., Milwaukee, Wis. <sup>14</sup>C-labeled CCl<sub>4</sub> (3.4 mCi/mMol) was obtained from NEN DuPont (Boston, Mass.). Carbon tetrachloride was monitored by gas chromatography as previously described (Tatara et al, "Applied Environmental Microbiology", Vol. 59, pages 2126-2131 (1993)). Anions were determined by ion chromatography (EPA Method 300). pH was measured with an Orion 701 pH meter. Protein was determined by the modified Lowery method (Markwell et al, "Methods of Enzymology", Vol. 72, pages 296-301 (1981)).

Microbial transformation of hazardous wastes can be effected by *Pseudomonas stutzeri* KC (DSM deposit no. 7136) (ATCC deposit number 55595; U.S. Pat. No. 5,602,036) a denitrifying bacterium that converts carbon tetrachloride (CT) to carbon dioxide (40-50%) and nonvolatile compounds (45-55%) without production of detectable chloroform under most growth conditions (Criddle et al, "Applied Environmental Microbiology", Vol. 56, pages 3240-3246 (1990); and Dybas et al, "Applied Environmental Microbiology", Vol. 61, pages 758-762 (1995). This experiment was to determine whether *P. stutzeri* KC could degrade carbon tetrachloride with minimal production of chloroform when vegetable oil was supplied as the carbon source. Vegetable oil was the source for the solid hydrogenated oil beads in the following Examples.

FIG. 1 shows that vegetable oil can support carbon tetrachloride removal by *P. stutzeri* KC, and that the system was limited only by the supply of the electron acceptor (nitrate). FIG. 2 shows that no significant carbon tetrachloride degradation was observed for the Schoolcraft flora alone when provided vegetable oil. While the data demonstrates that vegetable oil is sufficient to effect carbon tetrachloride degradation by *P. stutzeri*, the rate of dissolution of the oil is fairly rapid, which results in an excessively rapid utilization of the oil and the generation of fermentation products and noxious substances (such as



H.sub.2 S) which adversely affects groundwater quality. To mitigate this problem the dissolution rate of any added carbon must be such that the level in solution does not exceed the rate of supply of electron acceptors such as nitrate or oxygen which sustain degradation without the production of noxious end products.

To limit the rate of dissolution and thereby prevent formation of unwanted byproducts, an approach was adopted that was based on the solid phase delivery/slow dissolution compositions of the present invention. The following Examples show: 1) hydrogenated cotton seed oil particles or beads, and 2) microporous heat fractured clay particles filled with base phosphate, vegetable shortening and microorganisms (*Pseudomonas stutzeri* stain KC), each in separate beads.

## EXAMPLE 2

This Example shows that solid hydrogenated oil particles can support growth of *P. stutzeri* KC and effect degradation of carbon tetrachloride. Groundwater (10 ml) from a carbon tetrachloride impacted section of an aquifer located in Schoolcraft, Mich. were dispensed in sterile 20 ml vials (microcosms). Hydrogenated solid cotton seed oil beads (1.2 mg), nitrate (240 ppm) and carbon tetrachloride (10 ppm) were added to the microcosms. Microcosms were inoculated with 0.1% (v/v) strain KC culture grown in nutrient broth.

The hydrogenated cotton seed oil particle system makes use of the calorie rich nature of an oil with a delivery system that controls solubility. Particles of hydrogenated cotton seed oil are shown to be capable of supporting carbon tetrachloride degradation by *P. stutzeri* KC. Aveda, Inc. produces solid particles of hydrogenated cotton seed oil in the 10 .mu.m-3 mm diameter size range. The particles can be provided with differing solubilities to generate more effective time release. These particles are produced by a process involving melt spraying (prilling) to produce particles of the required size. 300 micron diameter beads were used in these experiments. FIGS. 3 and 4 show that the solid hydrogenated cotton seed oil beads of the present invention can support carbon tetrachloride removal by *P. stutzeri* when supplied with an electron acceptor such as nitrate (nitrate utilization). The indigenous flora under the same conditions did not degrade carbon tetrachloride (FIG. 3) nor utilize the nitrate (FIG. 4). This experiment shows that the solid hydrogenated oil beads of the present invention are an effective source of carbon for *P. stutzeri* KC and will support *P. stutzeri* KC degradation of carbon tetrachloride.

## EXAMPLE 3

A porous bead controlled delivery system of the present invention was tested for ability to support carbon tetrachloride degradation by *P. stutzeri*. In these experiments, microporous heat fractured clay beads were used to deliver base, phosphate, acetate, vegetable shortening and *Pseudomonas* strain KC bacteria to environmental samples contaminated with carbon tetrachloride.

The microporous clay particles are manufactured by Einfach-Grun Hydroton (Eschborn, Germany). These particles are produced by heat fracturing clay beads to produce beads of low (0.6 g/ml) dry density which possess excellent capillary action, allowing uptake of liquid.

For all experiments particles (4 to 8 mm diameter) were washed 3 times with 18 Mohm resistance deionized water. To wash the internal pore structure, beads (40-100g) were placed in 1 liter deionized water, and a vacuum applied (25"Hg) for 5 minutes to degas particles. The water was exchanged 3 times, then particles were dried at 100.degree. C. Four different types of beads were produced.

1. Organic carbon loading of microporous particles. For carbon tetrachloride degradation studies, 8 mm clay particles were washed and dried as described above. Particles (40 g) were added to molten



<http://patft.uspto.gov/netacgi/nph-Parser?Sec1=PTO2&Sec2=HITOFF&p=1&u=/netahm...> 4/22/2003

## 2. Column Preparation

The column utilized is pasteurized for 24 hours prior to packing. Ottawa Sand and microporous particle mixtures are saturated packed to reduce entrapped air. Material is packed in 5 equal layers. Each layer is tamped 25 times with 1.2 kg hammer.

## 3. Falling-Head Permeability Tests

A standard falling head permeability test is utilized to measure the permeability coefficient,  $k$ , of the Ottawa Sand and clay particle mixture. The time is measured for a column of water to fall a determined height and related to the permeability by the following equation:

$$k = (aL/At) \ln(h_{\text{sub.0}}/h_{\text{sub.1}})$$

$k$  (cm/s): coefficient of permeability

$a$  (cm<sup>sub.2</sup>): cross-sectional area of stand pipe

$L$  (cm): length of column

$t$  (sec.): time required for column of water to fall

$A$  (cm<sup>sup.2</sup>): cross-sectional area of column

$h_{\text{sub.0}}$  (cm): initial height of water in stand pipe

$h_{\text{sub.1}}$ , (cm): final height of water in stand pipe

## 4. Data Reduction

A total of 5 columns are packed for each microporous particle fraction. Every column is weighed and oven dried to determine water content and porosity of Ottawa Sand and clay bead mixture. The permeability coefficients for each column are determined and averaged to yield one average  $k$  value for a given microporous particle fraction. A 90% confidence interval is determined based on the  $t$ -distribution with 4 degrees of freedom.

FIG. 7 shows the effect of microporous particles on the conductivity of sand as measured by the falling-head permeability test for different percentages by weight of beads. The figure shows that the  $k$  rises from approximately 0.03 at 0 percent by weight beads to a maximum of 0.05 at 10 percent by weight of beads and then falling to approximately 0.04 at 40 percent by weight of beads.

## EXAMPLE 5

This experiment was to determine the kinetics of the release of organic carbon from the microporous particles.

### 1. Preparation and Loading of Particles

Particles were washed and dried as described in Example 3. Molten vegetable shortening (CRISCO.RTM.) was added to the dry particles. Particles and shortening were set in a 60.degree. C.

oven. After a day of loading the remaining shortening was decanted and the particles were blotted dry. A loading level of 0.197 g shortening per bead was achieved.

## 2. Kinetics of Organic Carbon Release from Particles

Clay particles loaded with shortening as described above were shaken in vials containing 15 ml of deionized water at 150 rpm. Liquid samples were taken and the amount of organic carbon determined by Chemical Oxidation Demand (COD) measurements. A plot of COD versus time is shown in FIG. 8. After approximately 12 hours a liquid phase concentration of 60 ppm carbon was obtained. After an initial rapid release of carbon, the bulk solution concentration of carbon appeared to stabilize at 60 ppm.

### EXAMPLE 6

In some environments, toxic metals, such as chromium copper, zinc or cadmium, can limit the efficacy of bioremediation achievable using the slow-release particles. In such environments, additional particles were added to the slow-release composition to enable the removal of the toxic metals from solution. Examples of such particles include ion exchange beads, zeolite minerals with high ion exchange capacity, or other chelating particles.

### EXAMPLE 7

In some environments, it is desirable to increase the concentration of sorbed organics within the bioreactive zone including the slow-release composition. For example, some organics may be toxic at high aqueous concentration and rapid removal from the water phase can facilitate remediation. In other cases, it is desirable to concentrate organics that slowly degrade to increase their residence time within the treatment regime. For the above cases, particles that sorb organics, such as ion exchanged modified clays (U.S. Pat. No. 5,268,109) or activated carbon particles can be included in the slow-release composition.

### EXAMPLE 8

Delivery of slowly dissolving substrates can be more controlled when above-ground bioreactors are employed or when the particles are enclosed within cartridges or cassettes which are installed within the treatment regime and periodically removed for replenishment or reactivation.

In some instances, the microorganism colonizes the particle. This is particularly the case with the inert beads containing the nutrient medium.

It is intended that the foregoing description be only illustrative of the present invention and that the present invention be limited only by the hereinafter appended claims.

\* \* \* \* \*

